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DERIVATION OF THE BRAKE-SPECIFIC VENTILATION EQUATION AND AN OPERATING LOAD FACTOR EXPRESSION RELEVANT TO THE USE OF DIESEL MACHINERY UNDERGROUND

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DERIVATION OF THE BRAKE-SPECIFIC VENTILATION EQUATION AND AN OPERATING LOAD FACTOR EXPRESSION RELEVANT TO THE USE OF DIESEL MACHINERY UNDERGROUND

by

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ABSTRACT

This analysis suggests that the measurement of CO_2 in the dieselized environment of concern, along with knowledge of the ventilation rate in a given work area, irrespective of numbers and type of machines, will permit the ready determination of:

1) actual overall fuel consumption,
2) actual brake-specific ventilation,
3) operating brake horsepower, and
4) overall operating load factor.

This latter factor can also be thought of as a relative index of productivity, as well as a means of establishing ventilation reduction factors for certification-determined maximum ventilation requirements for a given operating situation.

KEYWORDS: diesel, ventilation, CO_2, load factor.

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DÉDUCTION DE L'ÉQUATION DÉCRIVANT LA VENTILATION AFFECTÉE AU FREINAGE ET D'UNE EXPRESSION DU FACTEUR DE CHARGE EFFECTIF APPLICABLE À L'UTILISATION DE MACHINERIE DIESEL DANS LES MINES SOUTERRAINES

par

E. D. Dainty*

RÉSUMÉ

Selon cette analyse, la teneur en CO_2 dans le milieu où se trouve la machinerie diesel, ainsi que le taux de ventilation dans un secteur de travail donné, permettront, quel que soit le nombre et le type de machines, de déterminer rapidement

1) la consommation globale réelle de carburant,
2) la ventilation réellement affectée au freinage,
3) la valeur effective de la puissance au frein et
4) le facteur de charge effectif global.

On peut également considérer ce dernier facteur comme un indice de productivité et comme un moyen permettant d'établir des facteurs de réduction de la ventilation pour les exigences de ventilation maximale déterminées par la certification dans les conditions de fonctionnement données.

MOTS CLÉS : diesel, ventilation, CO_2, facteur de charge.Chercheur, Laboratoire canadien de recherche sur les atmosphères explosives, Laboratoires de recherche minière, Centre canadien de la technologie des minéraux et de l'énergie, Énergie, Mines et Ressources, Canada, Ottawa.

INTRODUCTION

As a result of examination of the fundamentals (CO_2 and ventilation rates) associated with the use of diesel machines underground, it became clear that relatively simple equations could be employed to determine fuel consumption, brake-specific ventilation and operating load factor. This latter index should prove useful in discussions regarding appropriate operating correction factors to maximum ventilation rates prescribed as a result of certification of diesel engines using the Air Quality Index as the measure of toxicity.

The following analysis derives these expressions and checks the result using engine operating data.

SYMBOLS, DIMENSIONS AND ASSUMED ENGINE OPERATING CONDITIONS

bhp	- power output	- 125 bhp (max)
Wf	- fuel consumption	- 50 lb/h
BSFC	- approximate brake-specific fuel consumption	- 0.4 lb/bhp.h
Wa	- air flow	- 1000 lb/h
f/a	- fuel/air ratio	- 0.050
Wdxg	- dry exhaust gas flow	- 990 lb/h
CO_2	- CO_2dxg (dry exhaust gas)	- 10.9% vol dry
	- CO2mix (mine environment)	- 0.135% vol dry
C	- weight of carbon in fuel	- 0.86 lb/lb fuel
MW	- molecular weight - $MWCO_2$	- 44
	- MWdxg	- 30
Qdxg	- dry exhaust volume flow	- 211 cfm
Qair	- fresh diluting air flow	- 23,050 cfm
ρdxg	- density	- 0.0777 lb/ft3
BSV	- brake-specific ventilation	- cfm/bhp

DERIVATION OF THE CO_2 CONCENTRATION IN DRY EXHAUST GAS

From unitary analysis:

$$CO_2\ dxg = \frac{1b\ fuel}{hr} \times \frac{1b\ C}{1b\ fuel} \times \frac{1b\ CO_2}{1b\ C} \times \frac{MWdxg}{MWCO_2} \times \frac{hr}{1b\ dxg} \times 100\%$$

$$= Wf \times 0.86 \times 44/12 \times 30/44 \times 1/Wdxg \times 100$$

$$= 215\ \frac{Wf}{Wdxg} = 215 \times \frac{50}{990} = 10.9\%$$

therefore, $$Wdxg = 215\ \frac{Wf}{CO_2 dxg}$$

Also, $W = \rho.Q$ and $Q = W/\rho$, where,

$$\rho dxg = \frac{P}{R \times T} = \frac{14.696 \times 144}{1545/30 \times (460 + 70)} = 0.0777\ lb/ft3, \text{ then}$$

$$Qdxg = Wdxg \times \frac{1}{60 \times 0.0777} = \frac{215\ Wf}{CO_2 dxg} \times \frac{1}{60 \times 0.077}$$

$$= \frac{46.1 \times Wf}{CO2dxg}\ cfm = \frac{46.1 \times 50}{10.9} = 211\ cfm \qquad [1]$$

ALTERNATIVE DERIVATION FOR DRY EXHAUST GAS CO_2 AND GAS FLOW RATE

From a CO_2 balance for the mine operating area in question:

CO_2 in dxg + CO_2 in dilution air = CO_2 in mine environment

$$Qdxg \times CO_2 dxg + Qair \times CO_2 air = (Qdxg + Qair) \times CO_2 mix$$

$$= Qdxg \times CO_2 mix + Qair \times CO_2 mix$$

$$Qdxg \times CO_2 dxg = Qair \times CO_2 mix - 0.035 \times Qair + Qdxg \times CO_2 mix$$

$$CO_2 dxg = \frac{Qair}{Qdxg} \times CO_2 mix - 0.035\ \frac{Qair}{Qdxg} + \frac{Qdxg}{Qdxg} \times CO_2 mix$$

$$= CO_2 mix \left[\frac{Qair}{Qdxg} + \frac{Qdxg}{Qdxg}\right] - \frac{Qair}{Qdxg} \times 0.035$$

$$= CO_2 mix \left[\frac{Qair}{Qdxg} + 1\right] - 0.035\ \frac{Qair}{Qdxg}$$

Qair/Qdxg varies, but is frequently of the order of 100, and is therefore much larger than 1. Consequently, omitting the 1 ' the first term, causes a small error (approximately -1.7% in this case), resulting in the followingsimplified expression:

$$CO_2dxg = \frac{Qair}{Qdxg} \times (CO_2mix - 0.035)$$

Therefore,

$$Qdxg = Qair \times \frac{CO_2mix - 0.035}{CO_2dxg} \qquad [2]$$

DETERMINATION OF THE DILUTING AIR FLOW RATE EXPRESSION

Equating [2] to [1] above, gives:

$$Qdxg = \frac{46.1 \times Wf}{CO_2dxg} = Qair \times \frac{CO_2mix - 0.035}{CO_2dxg}$$

so that

$$Qair = \frac{46.1 \times Wf}{CO_2mix - 0.035} \text{ cfm} \qquad [3]$$

$$= \frac{46.1 \times 50}{0.135 - 0.035} = 23{,}050 \text{ cfm}$$

Equation [3] is essentially the expression presented by Johnson in Paper #3 of CIM Special Volume #36, page 457.

CALCULATION OF FUEL RATE, BRAKE SECIFIC VENTILATION & LOAD FACTOR

Therefore, if the CO_2 in the ambient environment (after mixing of the exhaust gas with the diluting air), is measured, and the ventilation rate is known, then the fuel consumed can be calculated as follows:

$$Wf = Qair\ (CO_2mix - 0.035)/\ 46.1 \qquad [4]$$

$$23{,}050 \times (0.135 - 0.035)/\ 46.1 = 50 \text{ lb/hr}$$

If both sides of [3] are divided by the operating power, then an expression for the operating brake-specific ventilation (BSV) results, as follows:

$$BSV = \frac{Qair}{\text{operating bhp}} = \frac{46.1\ Wf/bhp}{CO_2mix - 0.035} = \frac{46.1 \times BSFC}{CO_2mix - 0.035} \qquad [5]$$

$$= \frac{46.1 \times 50/125}{0.135 - 0.035} = 184.4\ \text{cfm/bhp}$$

where the brake-specific fuel consumption (BSFC) is usually about 0.4 lb fuel/bhp.h at full load operating conditions.

Therefore,

$$\text{operating bhp} = \frac{Wf}{BSFC} = \frac{50}{0.40} = 125\ \text{bhp}$$

$$= \frac{Qair\ (CO_2mix - 0.035)}{46.1 \times BSFC} \qquad [6]$$

$$= \frac{23{,}050\ (0.135 - 0.035)}{46.1 \times 0.4} = 125\ \text{bhp}$$

The operating values assumed apply to a fully loaded mine engine. The operating horsepower will always be less than this maximum. It is therefore possible to determine the operating load factor (utilization factor or productivity index) of the machinery in an underground work area by measuring the ventilation and the ambient CO_2 in the work area exit, as indicated by the following equation:

$$\text{operating load factor} = \frac{\text{operating bhp}}{\text{installed bhp}} = \frac{Qair\ (CO_2mix - 0.035)}{46.1 \times 0.4 \times \text{installed bhp}} \qquad [7]$$

CO_2 MEASUREMENT CONTROLS BRAKE SPECIFIC VENTILATION RATE

Equation [5] can be used to generate a CO_2 vs the brake-specific ventilation characteristic curve as in the following table:

CO_2mix (%)	CO_2mix-0.035 (%)	BSV (cfm/bhp)
0.085	0.050	369
0.135	0.100	184
0.185	0.150	123
0.235	0.200	92
0.285	0.250	74
0.335	0.300	61

When this characteristic curve is used in conjunction with maximumcontrol CO_2 values (for an AQI = 3) determined for exhaust treatment devices, then a powerful environmental control characteristic emerges. The following table gives calculated control CO_2 values for four treatment systems applied to Deutz 714 and 413 series engines:

Treatment	Control CO_2
catalytic purifier	0.074
untreated Deutz	0.086
hockey stick exhaust pipe	0.105
unassisted ceramic filter	0.237

The characteristic curve of Fig. 1 indicates the cfm/bhp required to maintain an AQI of three for each type of treatment system.

CONCLUSIONS

The above analysis suggests that the measurement of CO2 in the diesel environment of concern, along with knowledge of the ventilation rate in a given work area, irrespective of numbers and type of machines, will permit the ready determination of:

1) actual overall fuel consumption,
2) actual brake-specific ventilation,

3) operating brake horsepower, and

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This latter factor can also be thought of as a relative index of productivity, as well as a means of establishing ventilation reduction factors for certification-determined maximum ventilation requirements for a given operating situation.

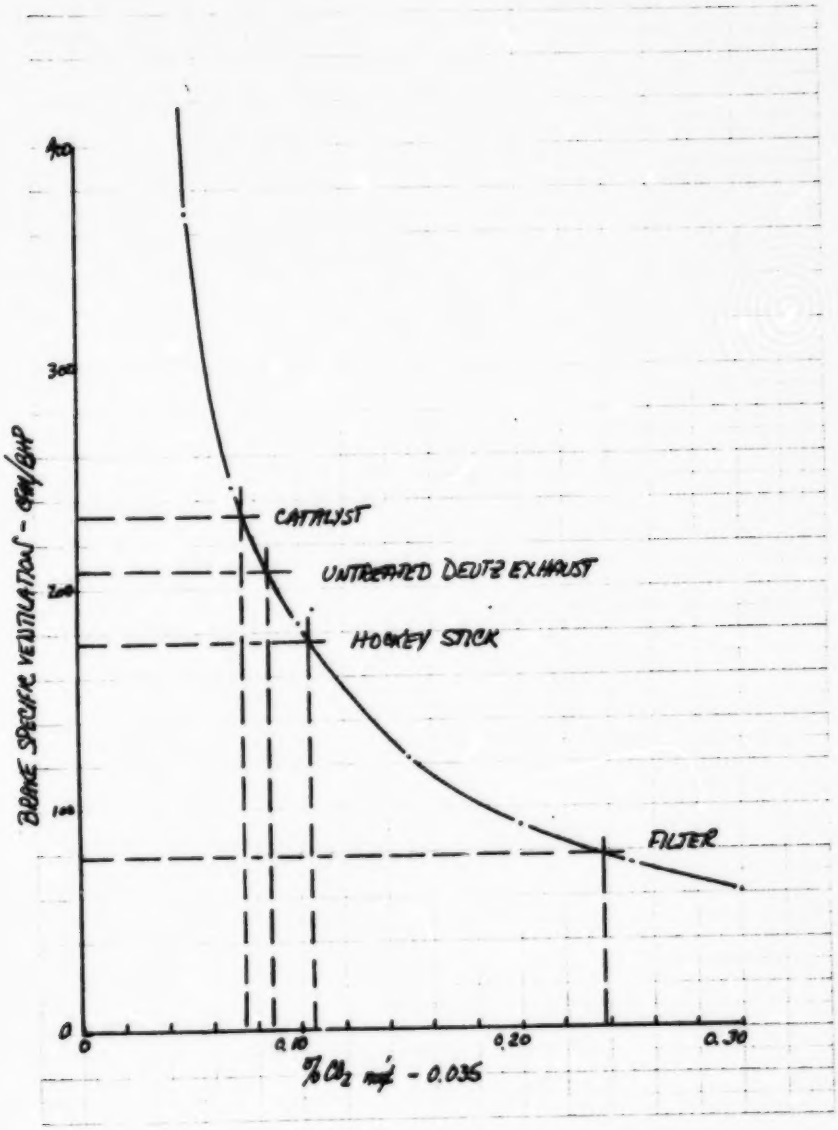

Fig. 1 - RELATIONSHIP BETWEEN CO2 AND BRAKE-SPECIFIC VENTILATION FOR FOUR TREATMENT METHODS (AQI = 3)